RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF STRESS-RUPTURE AND TENSILE STRENGTH OF THERMENOL, AN IRON-ALUMINUM ALLOY

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

A preliminary investigation was conducted to determine the stress-rupture life at 1100° and 1200° F, the room-temperature tensile strength, and the bend ductility of Thermenol (an iron-aluminum-base alloy). This alloy is made oxidation-resistant through the use of aluminum. The results of the investigation show that Thermenol had a 100-hour stress-rupture strength of 19,300 psi at 1200° F and 35,500 psi at 1100° F. The room-temperature tensile strength was 62,050 psi with 3-percent elongation in a 3/4-inch-gage length. Angles of bend causing failure at room temperature in the longitudinal and transverse directions were about equal, ranging from 34° to 56° and 34° to 48°, respectively.

INTRODUCTION

Thermenol, a nonstrategic iron-base alloy containing 16 percent aluminum was developed by the Naval Ordnance Laboratory as an oxidation-resistant alloy that may be suitable for use at elevated temperatures. The research reported herein was a preliminary investigation conducted by the NACA Lewis laboratory in cooperation with the Naval Ordnance Laboratory to determine stress-rupture properties of the alloy in sheet form at stresses ranging from 10,000 to 50,000 psi at temperatures of 1100° and 1200° F. Room-temperature tensile strength and bend ductility of the alloy were also determined. These data represent the first elevated-temperature testing of the iron-aluminum-base alloys and thus, of course, do not necessarily represent the full potential of this class of alloy.

APPARATUS AND PROCEDURE

Heat-treated Thermenol in the form of 0.020-inch sheet material submitted for evaluation was reported to have the following chemical analysis:

Aluminum . . . . 16 percent
Molybdenum . . . . 3.3 percent
Iron . . . . Remainder

Thermenol was produced from electrolytic iron, 99.99-percent-grade aluminum, and high-purity molybdenum by vacuum-melting. The melt was cast into ingots, which were subsequently hot-rolled to size. The fabrication of Thermenol is similar to that of Alfenol (16-percent-aluminum - iron alloy), described in reference 1. The sheet material had been heat-treated at 1050° C (1922° F) for 2 hours and air-cooled.

The type of stress-rupture and tensile test specimen used in this investigation is shown in figure 1. Five stress-rupture tests were made at 1200° F, nine stress-rupture tests at 1100° F, and four tensile tests at room temperature. The initial stresses (at constant load) ranged from 10,000 to 30,000 psi at 1200° F, and from 10,000 to 50,000 psi at 1100° F.

Elongation of stress-rupture and tensile test specimens was assumed to occur only in the 3/4-inch-gage length section, but measurements were taken at the shoulders of the specimens, which were approximately 1.60 inches apart.

The material contained stringers in the longitudinal direction and was suspected to have directional properties. Qualitative bend tests (bending by hand) indicated that the metal appeared to be less ductile in the transverse direction. In order to determine a numerical value for bend ductility, a quasi-quantitative bend test was made on longitudinal and transverse test sections of 0.020 by 0.22 by 1.0 inch in the test rig schematically shown in figure 2. The test specimen was supported on titanium carbide blocks spaced 13/16 inch apart, and the bending load was applied to the center of the specimen through a plunger having a 0.1875-inch-diameter drill-rod face (0.0938-inch radius of bend). The rate of loading was not constant, because the bending force was applied by hand. The angle of bend was determined after failure by measuring the angle formed by the straight sections of the reassembled specimen.

RESULTS AND DISCUSSION

The results of the stress-rupture tests are shown in table I and in figure 3. In order to furnish a basis for comparison, stress-rupture data for the austenitic stainless steels AISI 310 and 321 are also plotted in figure 3. The stress-rupture data at 1100° F were obtained from reference 2 for the AISI 310 and from reference 3 for the AISI 321. The 1200° F data on both stainless steels were obtained from the Thomson Laboratory of the General Electric Company (West Lynn, Mass.). AISI 310 is a 25-percent-chromium, 20-percent-nickel stainless steel with approximately 0.25 percent carbon; and AISI 321 is a titanium-stabilized 18-percent-chromium, 10-percent-nickel stainless steel with 0.1 percent maximum carbon.

At 1200° F (fig. 3(a)), the stress-rupture life of Thermenol is less than that of AISI 321 stainless steel and greater than that of AISI 310 stainless steel for times less than 100 hours. For times greater than 100 hours, the stress-rupture strength of Thermenol is below that of both stainless steels. At 1100° F (fig. 3(b)), the stress-rupture strength of Thermenol is essentially equal to the strengths of the two stainless steels. For further convenience, the stress to produce rupture in 100 or 1000 hours at 1100° and 1200° F for each alloy is shown in the following table:

Alloy	Temperature, °F			
	1100		1200	
	Stress to produce rupture, psi			
	100 hr	1000 hr	100 hr	1000 hr
Thermenol	35,500	23,000	19,300	10,000
AISI 310	31,700	25,000	19,000	13,700
AISI 321	40,000	26,000	26,000	17,400

The elongations of stress-rupture specimens are listed in table I. At 1200° F, elongations ranged from 54 to 12 percent as the stress increased from 15,000 to 30,000 psi. The specimen stressed at 10,000 psi yielded an elongation of 121 percent, based on the 3/4-inch-gage length. This specimen elongated appreciably in the shoulders; and, since there is no convenient way of correcting for this measurement, it was deemed best, though incorrect, to report the elongation as occurring in the gage length.

At 1100° F, elongations ranged from 12 to 62 percent in the failed specimens. The two unfailed specimens showed elongations of 2 and 10 percent in 2010 hours at 10,000 and 15,000 psi, respectively.

In all the stress-rupture tests some creep did occur in the radii beyond the 3/4-inch-gage length and is incorporated in the reported data; thus, the results are slightly in error.

Room-temperature tensile strengths of four specimens of Thermenol are shown in table II. The average tensile strength for Thermenol is 62,050 psi with an average elongation of 3 percent. Thermenol has lower room-temperature tensile strength than either AISI 310 (92,000 psi) or 321 stainless steel (85,000 psi) and is considerably more brittle, having an average elongation of only 3 percent, compared with 47 percent for AISI 310 and 58 percent for AISI 321. The results of the room-temperature bend tests are listed in table III. The angles of bend (measured after failure) around an 0.0938-inch radius (4.68 times thickness of sheet) ranged from 34° to 48° in the transverse test and from 34° to 56° in the longitudinal test. Data from this test do not specifically indicate that the material is anisotropic in respect to bend ductility.

SUMMARY OF RESULTS

The results of the investigation show that Thermenol possesses the following properties:

1. At 1200° F, it has a 100-hour stress-rupture strength of 19,300 psi. This value is between the strength values for AISI 310 and 321 stainless steels (19,000 and 26,000 psi, respectively). At times beyond 100 hours, it is inferior to both stainless steels. 3407

2. At 1100° F, it has stress-rupture life roughly equivalent to that of the stainless steels (AISI 310 and 321), the 100-hour stress-rupture strength being 35,500 psi and the 1000-hour strength being 23,000 psi.

3. The average room-temperature tensile strength is 62,050 psi with 3-percent average elongation in a 3/4-inch-gage length, compared with 92,000 psi with 47-percent elongation (2-in.-gage length) for AISI 310 and 85,000 psi with 58-percent elongation (2-in.-gage length) for AISI 321 stainless steels.

4. A quasi-quantitative ductility test, which measured angle of bend in degrees, did not specifically indicate bend anisotropy between longitudinal and transverse directions. Ductilities in the longitudinal and transverse directions at room temperature were about equal, ranging from 34° to 56° and 34° to 48°, respectively.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 17, 1954

REFERENCES

1. Nachman, J. F., and Buehler, W. J.: The Fabrication and Properties of 16-Alfenol - A Non-strategic Aluminum-Iron Alloy. NAVORD Rep. 2819, U.S. Naval Ordnance Lab., Apr. 9, 1953.

2. Anon.: Digest of Steels for High Temperature Service. Fifth ed., Steel and Tube Div., The Timken Roller Bearing Co. (Canton, Ohio), 1946.

3. Smith, G. V., Dulis, E. J., and Houston, E. G.: Creep and Rupture of Several Chromium-Nickel Austenitic Stainless Steels. Trans. A.S.M., vol. 42, 1950, pp. 935-980.

4. Anon.: Steels for Elevated Temperature Service. United States Steel, Carnegie-Illinois Steel Corp., 1949.

TABLE I - STRESS-RUPTURE LIFE OF THERMENOL

Temperature, °F	Stress, psi	Life, hr	Elongation in 3/4-in. length, percent	Remarks
1200	10,000	[a]796	[b]121	At temperature 1054 hr
	15,000	250.1	54	
	20,000	72.9	38	
	25,000	47.6	23	
	30,000	16.6	12	
1100	10,000	[c]2010.4	[c]2	
	15,000	[c]2009.9	[c]10	
	20,000	1656.0	62	
	25,000	670.5	33	
	30,000	374.1	20	Broke in grips
	35,000	86.0	12	
	40,000	15.1	17	
	45,000	1.5	20	
	50,000	0.2	33	

[a]Corrected value; accidentally unloaded for 258 hr near end of test.

[b]Includes elongation of entire specimen.

[c]Test stopped; specimens unfailed.

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TABLE II - ROOM-TEMPERATURE ULTIMATE STRENGTH OF THERMENOL

COMPARED WITH AISI 310 AND 321

Alloy	Stress, psi	Elongation in 3/4-in.-gage length, percent	Remarks
Thermenol	65,400	2	
	64,800	4	
	60,500	2	Broke outside gage length
	57,500	4	Broke outside gage length
	Av. 62,050	Av. 3	
AISI 310	92,000	47 (2-in.-gage length, ref. 4)	
AISI 321	85,000	58 (2-in.-gage length, ref. 4)	

TABLE III - ANGLE OF BEND AFTER FAILURE

Specimen	Transverse bend test, deg	Longitudinal bend test, deg
1	48	47
	34	34
2	46	56
		48
3	48	56
	34	34

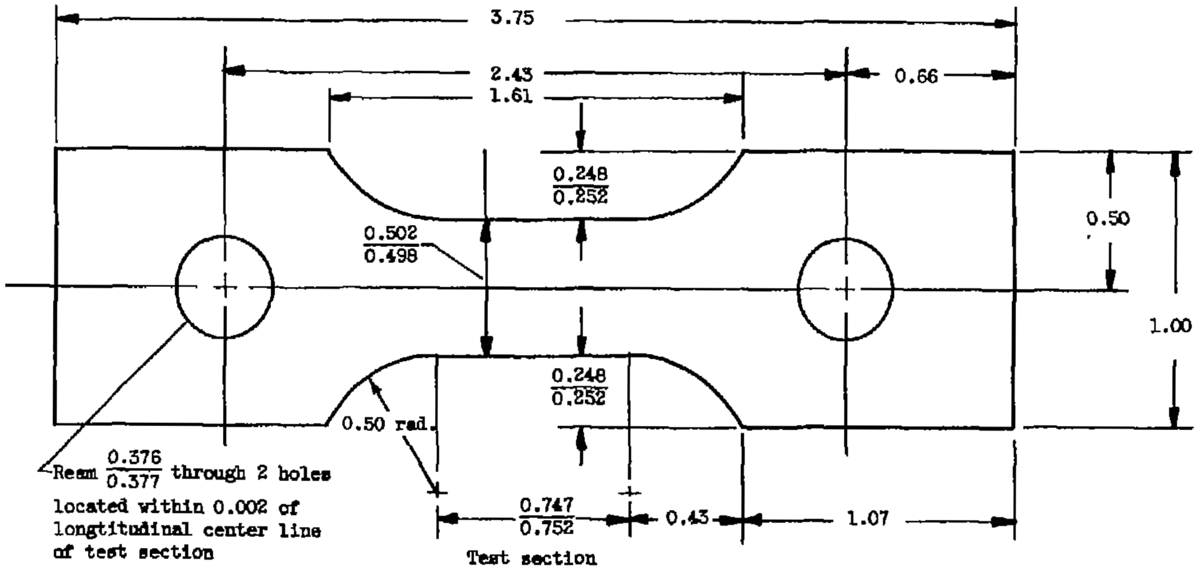


Figure 1. - Stress-rupture specimen (dimensions in inches). Thickness, 0.02 inch.

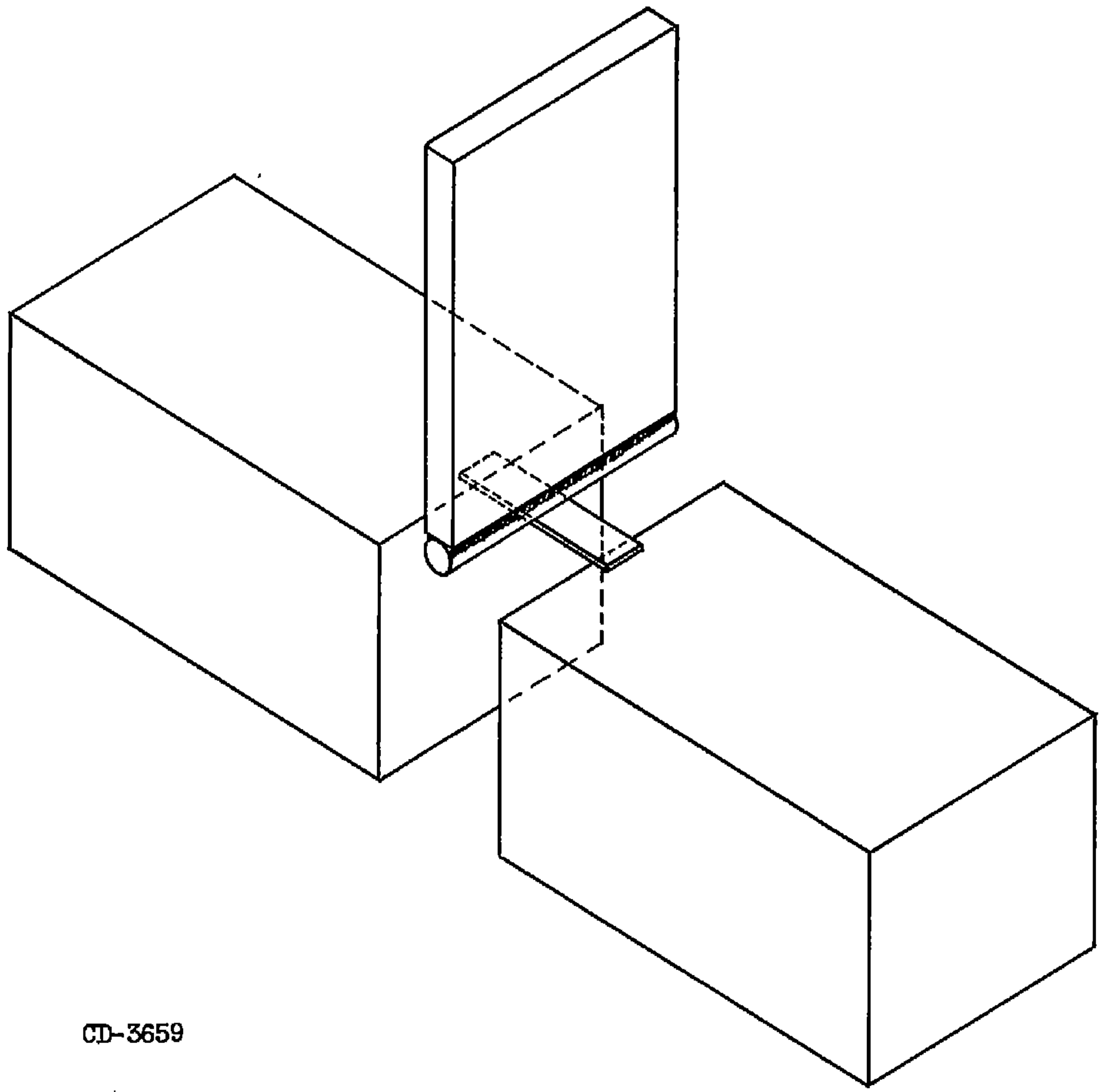
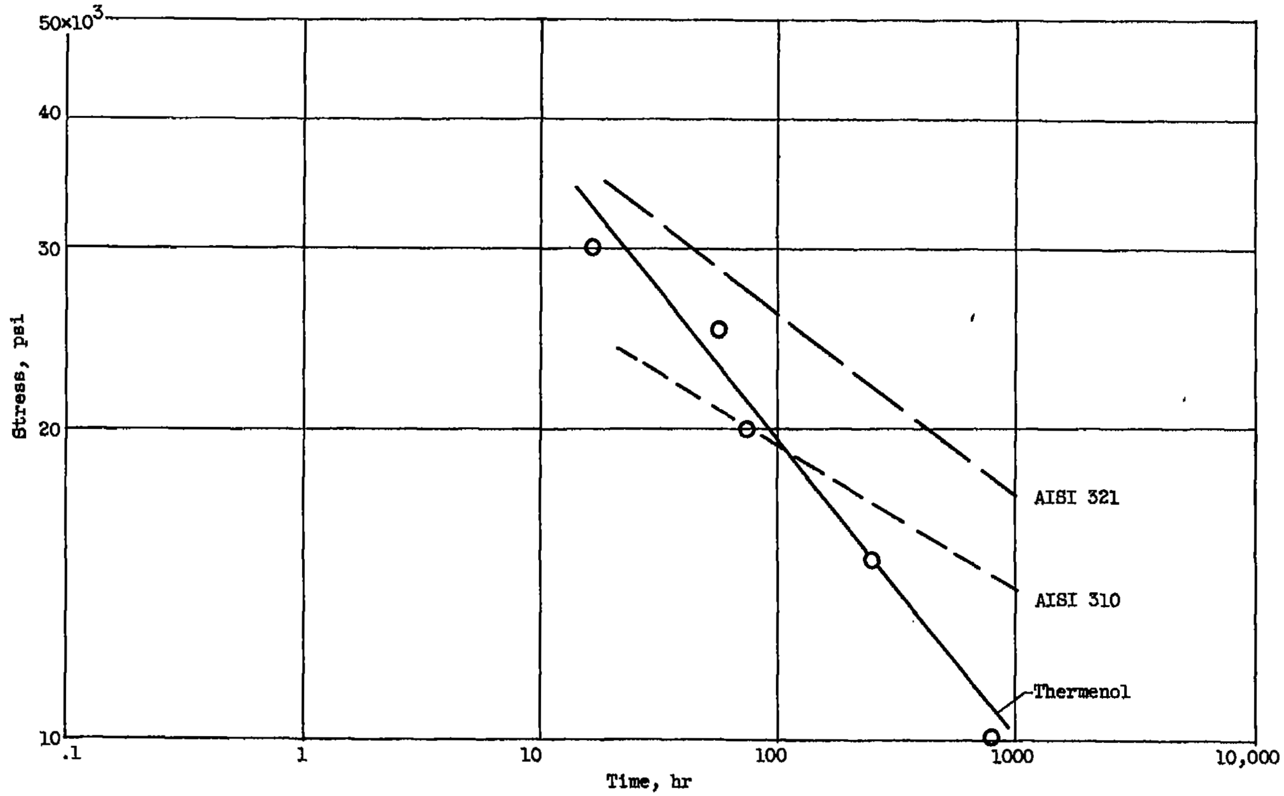
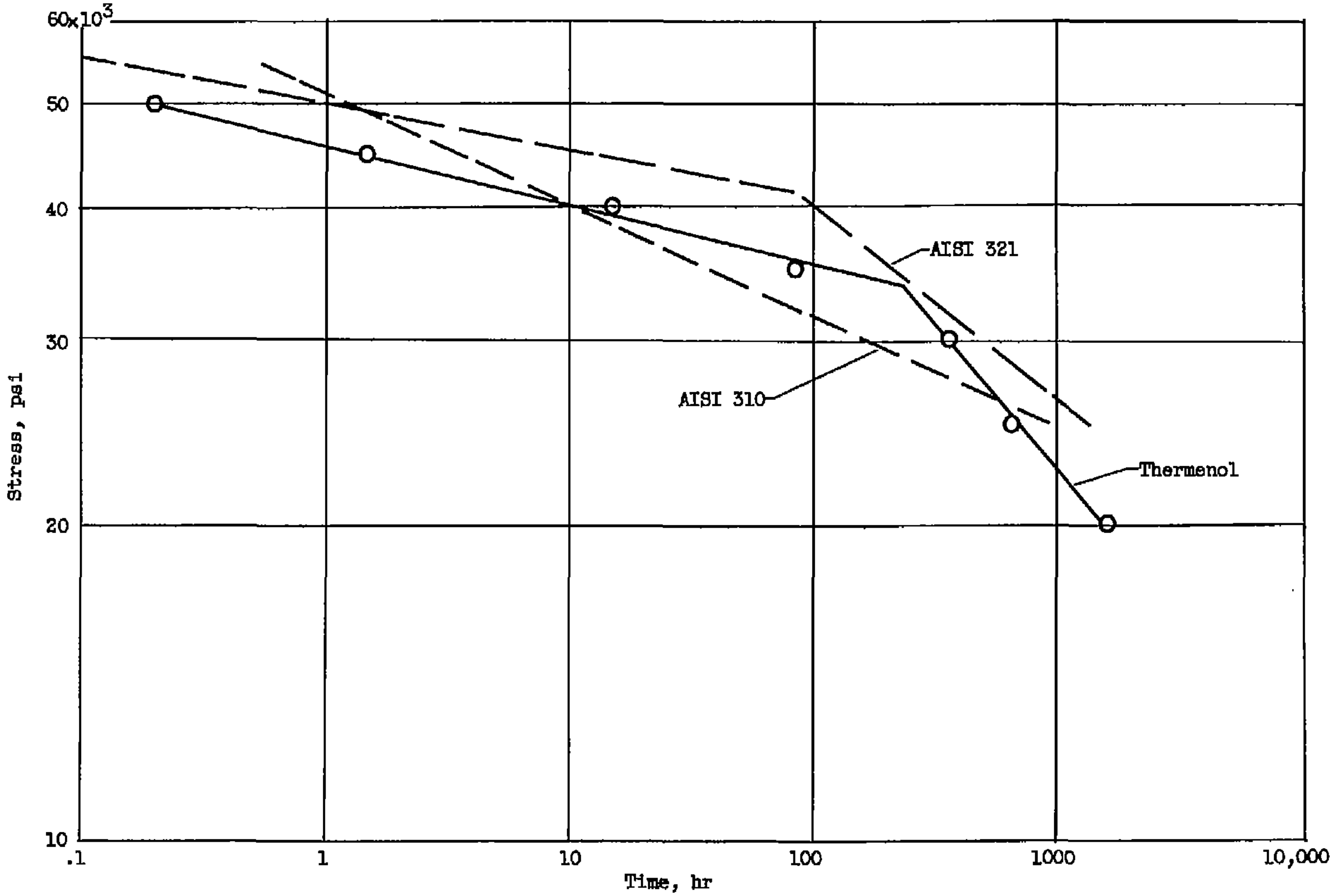


Figure 2. - Sketch of bend-test apparatus.



(a) Testing temperature, 1200° F.

Figure 3. - Comparison of stress-rupture life of Thermenol and AISI 310 and 321 stainless steels.



(b) Testing temperature, 1100° F.

Figure 3. - Concluded. Comparison of stress-rupture life of Thermenol and AISI 310 and 321 stainless steels.

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